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Estimating the benefits of joint occupation for street works in the UK

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The UK's local road infrastructure is subject to frequent openings to maintain and invest in buried infrastructure. Opening a road reduces its structural integrity, necessitates the implementation of traffic management and causes environmental pollution. These in turn can result in increased road use costs, adversely affect local business, cause social disbenefit, reduce road asset value and necessitate unplanned maintenance. There are therefore benefits to be gained from coordinating the openings of the highway in similar locations. Shared highway openings, however, are often not realised in practice for a number of reasons, including the lack of public accountability among infrastructure providers and the absence of appreciation for quantifying the benefits of joint occupation. To address this, this paper describes a novel rigorous procedure, based on multicriteria analysis, developed for Staffordshire County Council that evaluates the primary monetised and non-monetised economic, social, political and environmental benefits and costs associated with joint occupation and enables potential joint occupation schemes to be ranked. The use of the procedure is demonstrated by two joint occupation schemes in a rural and an urban area of Staffordshire. The work highlights the advantages of encouraging collaborative working among service providers to reduce costs and to increase asset life.

Notation

A_1	accident rate with traffic management (Pia/mvkm)
A_2	accident rate without works (Pia/mvkm)
A_{DL}	average daily loss per unit
A_{ADT}	annual average daily traffic
A_P	age of pavement (years)
A_{RS}	area of reinstatement (m^2)
A_V	amenity/annoyance value (£ per household per dB change)
C	total cycle time of the temporary signals
C_1	customer satisfaction indicator
C_2	collaborative working indicator
C_3	impact on amenity areas
C_4	innovation indicator
C_{apr1}	reduced capacity as a consequence of temporary traffic lights
C_j	savings of joint occupation associated with community indicators
C_M	cost of maintenance (patching/m^2)
C_O	original construction cost
D_1	user delay time (hour)
D_{BL}	daily business loss
E_1	total user delay cost
E_2	cost of reduced asset value
E_3	additional maintenance costs
E_4	cost of traffic management
E_5	impact on local businesses
E_6	cost of noise
E_7	cost of accidents
E_i	savings of joint occupation associated with economic indicators
g	effective green time for each lane
H_H	number of household experiencing an increase of noise of more than 5dB
H_{TV}	hourly traffic volume
H_V	health value (£ per household per dB change)
K_1	noise reduction factor
L_S	design life (years)
l	length of traffic management
N_{AU}	number of affected units
N_{Lbl}	noise levels prior to construction
N_{Lc}	noise levels during construction
P_1	reputation indicator
P_2	political cycles indicator
P_3	political interest indicator
P_4	location indicator
P_k	savings of joint occupation associated with political indicators
Q	traffic flow
T_{Md}	traffic management daily rate
t	estimated duration of the street works
V_{jo}	prioritisation index
W_c	relative importance (weighting) of the community indicators
W_e	relative importance (weighting) of the economic indicators
W_p	relative importance (weighting) of the political indicators
X	traffic ratio

Introduction

The UK has a diverse network of utility and cable infrastructure (gas, electricity, water and communications) that is housed within its road infrastructure. In 2015–2016, the number of street work openings, to maintain or introduce new utilities, on local roads in England and Wales was approximately 2·53 million (an increase of 13% from the previous year) (AIA, 2016). Openings often result in, among other things, traffic congestion, noise and road deterioration. It is estimated that openings reduce the structural life of roads by approximately 30%, and as a result, local authorities (LAs) in England and Wales spent, on average, 13% of their maintenance budgets for 2015–2016 on premature road maintenance that the openings necessitated (AIA, 2016).

The coordination of street works can reduce, particularly where works in the same location are carried out under joint occupation, the socio-economic costs of street works. The New Roads and Street Works Act 1991 (as amended by the Traffic Management Act 2004) governs street works and requires an LA to use its 'best endeavours' to coordinate street works and similarly requires a utility to co-operate in this with the LA and with other utilities.

Despite such legislation, asset owners have a mixed record of coordinating street works, and in circumstances where collaborative works have been undertaken, lessons learnt from the benefits of collaboration have not necessarily been widely shared. This can result in more openings in the highway than are necessary, resulting in increased financial costs to LAs, as mentioned earlier, as well as unnecessary associated economic and social costs to the general public.

To address these issues and facilitate joint occupation working, Staffordshire County Council has developed a novel tool for enabling the quantification of the benefits of joint occupation schemes and by so doing provide a means of ranking joint occupation scheme opportunities so that resources can be prioritised. The development and application of the tool is described in this paper.

Valuation approaches

The disruption due to highway openings can negatively impact (*a*) the road user (e.g. delay costs, increased vehicle operating costs, road safety), (*b*) local businesses (e.g. lack of footfall and increased delivery costs from diversions and street closures), (*c*) residents (e.g. health disbenefits associated with traffic and noise pollution, safety), (*d*) the environment (e.g. pollution), (*e*) road authority costs (e.g. unplanned maintenance resulting from road deterioration that can occur in the vicinity of an opening), (*f*) the capital value of the road network and (*g*) political interest. A number of techniques have been proposed in the literature to evaluate these impacts, and some of the available techniques are summarised in Table 1.

Techniques that apportion monetary values can be categorised as follows.

- Direct techniques: These determine the costs directly from a loss that can be valued (e.g. increased fuel consumption costs, sales trends for the affected businesses under loss of productivity).
- Indirect techniques: Costs are determined from the resulting cost impact on another good (e.g. long-term traffic impacts on house prices).

Direct valuation techniques provide measurable and transparent costs that are less open to dispute and where possible should be utilised. However, their use often requires the collection of a large volume of data, which is not always available. For example, the quantification of the loss of productivity experienced by local businesses requires data that are unlikely to be available until the completion of the works, should the businesses be willing to divulge the information.

Project appraisal

Where indicators of value can be monetised, cost-effectiveness analysis or cost–benefit analysis is typically used in the UK for project appraisal. The former is associated with comparing the costs of alternative activities of providing similar output, while the latter considers the financial costs and benefits of particular activities (DCLG, 2009).

To facilitate decision making in a consistent way, where there are large amounts of complex information and conflicting evaluation criteria, project appraisal approaches based on multicriteria analysis (MCA) are recommended by the British standard for risk management, BS EN 31010:2010 (BSI, 2010), and are widely used in practice (Dey, 2003). A useful description of a large number of MCA techniques is provided by the Department for Communities and Local Government (DCLG, 2009).

Typically, MCA approaches use an explicit relative weighting system to collectively consider indicators that can and cannot be monetised. The weightings are often determined using expert judgement. For a project alternative, the value of a monetised indicator is the cost determined using an appropriate valuation technique. For non-monetised indicators, the value is determined, often again by expert judgement, by assigning relative weights to identified attributes according to the perceived benefit provided by each alternative project. The use of expert judgement in MCA approaches allows for structure, openness, experience and knowledge to be incorporated into the decision-making process (DCLG, 2009).

A number of highway-related applications of MCA are reported in the literature. Examples include sustainability assessment (Bojković *et al.*, 2010), environmental impact assessment (Rogers and Bruen, 1998), sustainability evaluation of urban underground space (Curiel-Esparza and Canto-Perello, 2013; Makana, 2016), selection of trenchless construction methods (Islam, 2013), sustainable transportation (Zietsman *et al.*, 2006), strategic level assessment of transportation schemes (Pearman *et al.*, 1997), selection of small-scale highway improvements (Pearman *et al.*, 1989), assessment of low-volume road schemes (Millan, 2016),

Table 1. Valuation approaches

Category		Method	Description	Example of use pertinent to study	References
Monitory	Direct valuation	Loss of productivity	Used to quantify a reduction in the production of goods or provision of services due to roadworks	(*a*) Time-dependent social costs (*b*) Productivity reduction factor – for example, caused by noise pollution (*c*) Impact on local businesses	(*a*) Yu and Lo (2005) (*b*, *c*) Gilchrist and Allouche (2005)
		Human capital	Considers the value of health or loss of earnings, focusing on the impact of changes on human productivity rather than production of goods	(*a*) Noise impacts on health (*b*) Reduced life expectancy (*c*) Road traffic accidents (*d*) Road rage cost (*e*) Loss of sales for businesses	(*a*) IGCB(N) (2010), Morgan *et al*. (2011) (*b*) Babisch (2006), IGCB(N) (2010) (*c*) Coombe and Turner (1989), Hayes and Taylor (1993) (*d*, *e*) Gilchrist and Allouche (2005)
		Replacement cost	Evaluates loss of asset value and the cost of reduced pavement service life due to the number of openings made in the highway	(*a*) Long-term pavement damage (*b*) Additional travel distance (*c*) Capital value of road asset	(*a*) McHale (2013) (*b*) Gilchrist and Allouche (2005) (*c*) Burrow *et al*. (2013), Odoki *et al*. (2013), Robinson (2008)
		Lane closure cost	A hybrid between direct and indirect valuation techniques as it can include well-defined costs as indirectly measured costs	Lane rental and permit system (*a*) Highway notices and inspection (*b*) Traffic delays	(*a*, *b*) London First (2010), Herbsman (1995)
		Road user costs	Evaluates the economic costs of road use	(*a*) Travel time costs (*b*) Accident (*c*) Increased fuel consumption (*d*) Vehicle maintenance costs (*e*) Emissions	(*a*–*e*) Odoki *et al*. (2013) (*a*–*c*) Tighe *et al*. (1999) (*d*) Brady *et al*. (2001)
		Road authority costs	Maintenance costs resulting from road deterioration over a given period of analysis	(*a*) Maintenance costs (*b*) Maintenance of diversion routes used in road closures	(*a*) Odoki *et al*. (2013), Tighe *et al*. (2002) (*b*) Matthews and Allouche (2010)
	Indirect valuation	Hedonic pricing	Identifies price factors according to the proposition that price is determined by internal characteristics of a good being sold as well as exogenous affecting factors	(*a*) House prices (*b*) Noise	(*a*) Nelson (2008) (*b*) Levinson and Gillen (1998)
		Contingent valuation (stated preference)	A survey-based economic technique for the valuation of non-market resources	Willingness to pay for environmental improvements or to accept compensation for adverse impacts (e.g. caused by noise)	Boyce and Bried (1998) Odoki *et al*. (2013)
Non-monitory	Multicriteria analysis	Multiattribute utility theory	Uses a mathematical function to estimate by way of an integer scale the decision maker's overall valuation of an option in terms of the value of its performance on each of the separate criteria	(*a*) Sustainable transportation (*b*) Bridges and road construction quality assurance (QA)	(*a*) Zietsman *et al*. (2006) (*b*) Zavadskas *et al*. (2008)
		Analytical hierarchy process	Uses a pairwise comparison to assign weightings to criteria and options	Pavement maintenance priority ranking	Pourghasemi *et al*. (2012)
		Outranking methods	Founded on the concept that some options dominate others	(*a*) Land-use suitability assessment (*b*) Sustainability	(*a*) Joerin *et al*. (2001) (*b*) Bojković *et al*. (2010)

construction quality control of roads and bridges (Ramadhan *et al*., 1999), pavement maintenance prioritisation (Ramadhan *et al*., 1999), road network design (Atkinson *et al*., 2005; Cantarella and Vitetta, 2006), setting of road maintenance standards (Ortiz-Garcia *et al*., 2005) and investment strategy (Tudela *et al*., 2006).

However, there is a paucity in the literature of applications associated with the assessment of joint occupation schemes. Albeit, Schwarze (2015) proposed a linear programming model to capture the cost savings associated with coordinating trenching activities of different network operators and recommended, but did not use, MCA for comparing monetary values and time spent as a result of traffic delay. Tahon *et al*. (2011) also investigated the cost savings of a joint occupation in the construction of telecom and utility networks. However, their study did not consider the social aspects, such as customer satisfaction, of such a co-operation, a gap that this study addresses.

Requirements

Roadworks undertaken by LAs are governed by the Highways Act 1980, and legislation for street works is specified in the New Roads and Street Works Act 1991, as amended by the Traffic Management Act 2004 (Department for Transport, 2012). Under the New Roads and Street Works Act 1991, public utilities are able, by way of a statutory right or a licence, to undertake openings without the approval of LAs, but they are also responsible for carrying out appropriate reinstatement to given standards. The 1991 act, however, empowers LAs to specify when reinstatements can take place; enables them to prohibit, for a given time period, openings in resurfaced roads; and allows the inspection of the quality of reinstatements and for remedial works to be specified if necessary.

As mentioned earlier, it is the responsibility of both street authorities and undertakers to seek opportunities for joint occupation, and this relies on the early notification of proposed works by all parties. The ability for undertakers to be proactive, however, is prohibited by statutory notice periods, the greatest of which is 3 months for a major works notice stipulated in the New Roads and Street Works Act 1991 (Department for Transport, 2012).

Highway occupation is governed through the New Roads and Street Works Act 1991 by a permit process to regulate works durations and to ensure that traffic disruption is minimised (Department for Transport, 2012). The New Roads and Street Works Act 1991 outlines the implementation of lane rental systems and charges for unreasonably prolonged occupation of the highway. The permit system requires one of the undertakers to take the lead role in joint occupation schemes, and that joint occupation requires an element of work that the lead undertaker is not familiar with presents a risk of the works overrunning. This discourages joint occupation. Joint occupation is further discouraged, as the process requires the street works authority to have an understanding of the various types of works carried out by all undertakers so that a reasonable duration can be determined.

Table 2. Staffordshire County Council conflict categorisation

Category	Description
1	Major conflict – multiple works/restriction
2	Major conflict – major works and restriction only
3	Medium conflict – standard works/restriction
4	Minor conflict – minor works/restriction
5	Network Management unit team to review

Against this background, Staffordshire County Council's Network Management team has sought to promote scheme coordination by organising annual coordination meetings to encourage undertakers to programme works 12 months in advance. This has been facilitated by using the roadworks.org platform that geospatially maps forward planning notifications (Elgin, 2017). Using this approach, conflicts are identified geographically, according to their locality, and are categorised in accordance with the criteria in Table 2.

The Network Management team then considers these conflicts, and potential joint occupation schemes are identified for discussion at the annual coordination meeting. This can be a laborious process and requires a number of assumptions to be made regarding the viability of a joint occupation scheme. As a result, undertakers tend to identify improvements solely on their asset management schedule without giving consideration to the benefits accruing from joint occupation. Consequently, opportunities for joint occupation are not embedded in infrastructure asset management processes.

Tool development

To address the earlier mentioned issues, Staffordshire County Council's Network Management team sought to develop a tool that can demonstrate the benefits of joint occupation and provide a means of ranking joint occupation scheme opportunities, by way of a single index, so that resources can be prioritised.

It was considered that the tool should combine indicators that can be monetised together with non-monetised indicators. It was decided to use the council's proposed key performance indicators (KPIs) as the basis for the non-monetised indicators since they are used to evaluate the contribution of service providers to the client's business plan and objectives. The KPIs were chosen to enable the contribution of the joint occupation scheme to improve performance to form part of the decision-making process. Seven indicators of economic performance and eight non-monetised KPIs in two categories, community and political, were identified as being common across all service providers (Table 3).

Technique selection

Following an initial review of the literature, three MCA approaches were identified for further consideration. These were the multiattribute utility theory (MAUT), the outranking method (OM) and the analytical hierarchy process (AHP) (see DCLG (2009) for further descriptions of these approaches). Each approach has advantages and disadvantages for the task at hand,

Table 3. List of indicators

	Tier 1 indicator	Reference	Tier 2 indicator	Description
Monetised	Economic	E_1	User delay	Cost of delay to the road users
		E_2	Reduced asset value	Road asset value reduction
		E_3	Increased asset maintenance	Increased cost of maintenance
		E_4	Traffic management	Cost of traffic management
		E_5	Impact on local businesses	Negative impact on local businesses and their associated loss
		E_6	Noise	Health and annoyance of noise
		E_7	Accidents	Cost of accident
Non-monetised	Community	C_1	Customer satisfaction	Divided into (*a*) commercial and (*b*) residential
		C_2	Collaborative working	Number of infrastructure service providers working in collaboration
		C_3	Impact on amenity areas	Impact of the works on amenity facilities in the local area (e.g. parks and schools)
		C_4	Innovation	Perceived efficiency savings through innovative practices to enable collaborative working
	Political	P_1	Reputation	Likeness of positive press coverage generated by the project
		P_2	Political cycles	Project sensitivity to the political climate due to upcoming elections (local or national)
		P_3	Political interest	Political interest in relation to standing of interested politicians (local, ward, cabinet member, Member of Parliament)
		P_4	Location	Sensitivity of residents action groups to the project location

and in order to choose an appropriate one, the selection criteria recommended by DCLG (2009) were used, which are

(*a*) internal consistency and logical soundness
(*b*) transparency
(*c*) ease of use
(*d*) data requirements
(*e*) resource requirements for the analysis process
(*f*) ability to provide an audit trail
(*g*) software availability.

All three approaches identified for further scrutiny may be considered to be consistent and logically sound (criterion (*a*) above), need similar data in that they require options to be specified and their performance to be assessed against a set of weighted indicators (criterion (*d*)), have similar resource requirements (criterion (*e*)) and could be programmed relatively easily (criterion (*g*)).

The MAUT approach requires the definition of marginal utility functions for each indicator of value, a non-trivial task; thus, it was considered to be impracticable for the relatively large number of indicators associated with the task in hand (criterion (*c*)) (Ortiz-Garcia *et al*., 2005).

The OM depends on the concept of a project alternative outranking, or dominating, another. Weighting factors are used to provide more influence to some indicators of value than others. An alternative is considered to outrank another if it outperforms the other on enough indicators of sufficient importance and is not outperformed by any other alternative by having a significantly inferior performance according to any of the indicators of value (DCLG, 2009; Rogers and Bruen, 1998). While OM approaches encourage strong interaction between decision makers, they are considered to be overly dependent on the arbitrarily defined concept of outranking and on how the outperformance thresholds are set and modified. Consequently, for non-expert users, OM approaches are considered to be less transparent (criterion (*a*)) and to provide a less clear audit trail (criterion (*d*)) (DCLG, 2009).

In AHP, the decision problem is disaggregated into a multilevel hierarchy of more easily understood subproblems. The main objective, or goal, is the highest level of the hierarchy and the sublevels of the hierarchy contain subobjectives to achieving the goal. The lowest level of the hierarchy consists of the project alternatives. Following the construction of the hierarchy, the relative contribution of each subobjective towards the objective in the layer immediately above is determined by pairwise comparison. The pairwise comparisons are transformed into a set of normalised weights by using the eigenvector procedure, details of which may be found in Saaty (1980). Thereafter, a project alternative's score (i.e. relative ability to achieve the main goal) is calculated as the sum of the products of the weights along each branch of the hierarchy.

For the task at hand, the AHP was considered to be more transparent and easier to use for the intended decision makers (criteria (*b*) and (*c*)), as it allows the relative importance of the weighting factors to be established straightforwardly and conveniently. This enables the decision maker to focus on discrete aspects of the problem, and it was considered to be able to take into account site data specific to the task at hand (DCLG, 2009; Ortiz-Garcia *et al*., 2005).

Technique development

Following the consultation process with Staffordshire County Council's Network Management team described earlier, seven economic, four community and four political indicators were identified and are described in Table 3. Accordingly, a hierarchy consisting of three levels was developed as shown in Figure 1.

Using the AHP methodology described earlier for a particular scheme, the net benefit of joint occupation, V_{jo}, was calculated as follows

$$V_{jo} = W_e \sum_{i=1}^{7} E_i + W_c \sum_{j=1}^{4} W_{cj} C_j + W_p \sum_{k=1}^{4} W_{pk} P_k \quad (1)$$

where E_i, C_j and P_k are the savings of joint occupation associated with the ith economic, jth community and kth political indicators, respectively; each has a value between 1 and 10; W_e, W_c and W_p are the relative importance (weighting) of the economic, community and political indicators, respectively, compared to each other – that is, $W_e + W_c + W_p = 1$; W_{cj} is the relative importance of the jth community indicator relative to all other community indicators; and W_{pk} is the relative importance of the kth political indicator relative to all other political indicators.

Each of the weighting factors was determined by way of pairwise comparison carried out by the Network Management team using the methodology described by Saaty (1980).

The cost savings of joint occupation associated with each of the seven economic indicators were calculated using the methods described in the following (see also Table 1). Thereafter, for the purpose of the AHP analysis, the cost savings were converted to values of 1–10, where £1 million = 10 and £0·1 million = 1, using the scale suggested by the Network Management team given in Table 4.

The sum of the savings associated with community, $\sum_1^4 C_j$, and political costs, $\sum_1^4 P_k$, were evaluated by determining a score between 1 and 10 (where 1 = very poor and 10 = very good) for each of their four contributing indicators of value (Table 3). To determine the score attributed to an indicator, the contribution of the proposed scheme to overall success was determined using a questionnaire (not described in this paper) provided to the Network Management team.

Calculation of monetised indicators

The costs of the seven monetised indicators of value were calculated using the methods described in the following subsections.

Table 4. Scale for converting total monetised indicator of value

Score	Economic cost saving: £
1	>0
2	>200 000
3	>300 000
4	>400 000
5	>500 000
6	>600 000
7	>700 000
8	>800 000
9	>900 000
10	>1 000 000

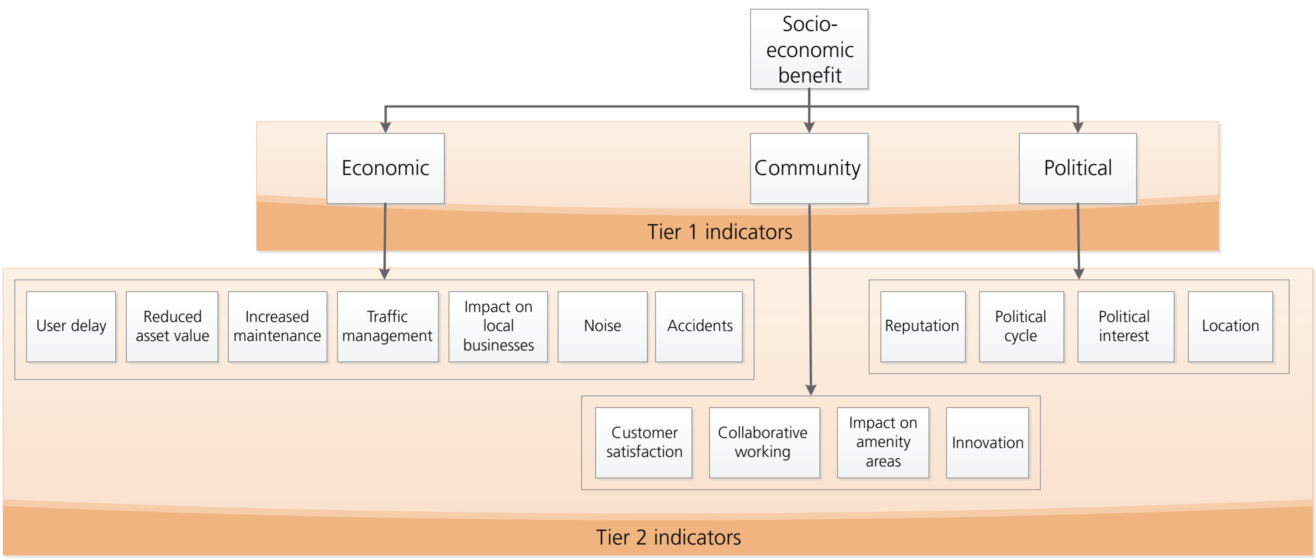

Figure 1. AHP ranking framework

User delay

Equation 2 developed by Tighe *et al*. (1999) was used for calculating user delay time (hours) D_1

$$D_1 = \frac{\left[0{\cdot}38C(1-g/C)^2\right]}{3600} + \frac{173X^2\left\{(X-1)+\left[(X-1)^2+16X/C_{\mathrm{ap}r1}\right]^{0{\cdot}5}\right\}}{3600} \quad (2)$$

where D_1 is the user delay time (h); g is the effective green time for each lane; C is the total cycle time of the temporary signals; $C_{\mathrm{ap}r1}$ is the reduced capacity as a consequence of temporary traffic lights (see Equation 3); and X is a ratio described in Equation 4.

The values in Equation 2 are based on the annual average daily traffic (A_{ADT}) (see Tighe *et al*. (1999) for associated values).

$$C_{\mathrm{ap}r1} = C_{\mathrm{ap}n1} \times \frac{g}{C} \quad (3)$$

where $C_{\mathrm{ap}n1}$ is the capacity per lane taken as 1400. $C_{\mathrm{ap}n1}$ is adjusted by a factor of 0·72 to account for the presence of heavy goods vehicle ($C_{\mathrm{ap}n1}$ = 1008).

$$X = \frac{H_{\mathrm{TV}}}{C_{\mathrm{ap}r1}} \quad (4)$$

where H_{TV} is the hourly traffic volume.

The total user delay cost (E_1) due to the presence of traffic management was calculated using the Department for Transport's (2013) *Transport Analysis Guidance* (webTag) as follows.

(*a*) Perform a modal split of the A_{ADT} into car, light-goods vehicle (LGVs), ordinary-goods vehicle 1 (OGV1) and ordinary-goods vehicle 2 (OGV2) according to the classified count (Highways Agency, 2006).
(*b*) Calculate the total delay (hours) for each mode by multiplying by the average delay time (D_1).
(*c*) Proportion the delay into work and non-work time for each mode.
(*d*) Multiply by the values of time for each mode type and journey purpose.
(*e*) Total the values of time to provide a total value of delay per day.
(*f*) Multiply the daily cost by the period of traffic management (or works duration) to determine the total user delay cost.

Reduced asset value

The cost of reduced asset value, E_2, was determined using the replacement method proposed by Matthews and Allouche (2010) as follows

$$E_2 = \left[C_{\mathrm{O}} \times \left(1 - \frac{A_{\mathrm{P}}}{L_{\mathrm{S}}}\right)\right] - \left\{C_{\mathrm{O}} \times \left[1 - \frac{A_{\mathrm{P}}}{(0{\cdot}3 \times A_{\mathrm{P}}) + (0{\cdot}7 \times L_{\mathrm{S}})}\right]\right\} \quad (5)$$

where C_{O} is the original construction cost; L_{S} is the design life (in years); A_{P} is the age of pavement when works were carried out (in years).

The factors 0·3 and 0·7 applied to A_{P} and L_{S}, respectively, reflect the 30% reduction in pavement service life caused by excavation, reported by Tighe *et al*. (2002).

Increased maintenance

Research undertaken by McHale (2013) showed that remedial treatment would be required for highway openings within 8 years. To allow for this, a simple equation proposed by Matthews and Allouche (2010) was used to determine additional maintenance costs (E_3)

$$E_3 = C_{\mathrm{M}} \times A_{\mathrm{RS}} \quad (6)$$

where C_{M} is the cost of maintenance indicated in maintenance contracts (in patching/m^2); A_{RS} is the area of reinstatement; area of the trench to be excavated (in m^2).

A limitation of the proposed equation is that it does not include the additional maintenance, which may be required for diversion routes as a result of their increased traffic levels. In the UK, diversion routes are required to be of the same category of road as the closed road and therefore can be assumed to be capable of withstanding similar traffic volumes. However, often, drivers select more direct routes than the official signed route along lower-category roads. The increased traffic can cause deterioration and therefore increase the maintenance costs.

Traffic management

The literature suggests that the costs of traffic management are a function of time and that it is a common practice to price the provision of traffic management as a daily rate (London First, 2010). Comprising rates for plant and labour and rates for hiring equipment including temporary signals and safety measures, the following equation was developed to calculate cost of traffic management, E_4

$$E_4 = T_{\mathrm{Md}} \times t \quad (7)$$

where T_{Md} is the traffic management daily rate; t is the estimated duration of the works.

Impact on local businesses

The loss of productivity technique was used to calculate the impact on local businesses by using the following equation (Yu and Lo, 2005)

$$D_{BL} = N_{AU} \times A_{DL} \tag{8}$$

where D_{BL} is the daily business loss; N_{AU} is the number of affected units; and A_{DL} is the average daily loss per unit.

The utilisation of Equation 8 requires the collection of survey data to record sales trends for the affected businesses. Attempts to capture the impacts of highway openings on local businesses are part of an ongoing project (see Hojjati *et al*. (2017)).

Noise

The cost of noise, E_6, takes into account health and annoyance of noise according to the following equation

$$E_6 = (N_{Lc} - N_{Lbl}) \times [H_V + (A_V \times K_1)] \times H_H \tag{9}$$

where N_{Lc} is the noise levels during construction; N_{Lbl} is the noise levels prior to construction; H_V is health value (in £ per household per decibel change); A_V is amenity/annoyance value (in £ per household per decibel change); K_1 is the reduction factor which reflects the duration of the noise; and H_H is the number of household experiencing an increase in noise of more than 5 dB (see BSI (2014)).

N_{Lc} was determined according to the UK code of practice for noise and vibration control on construction and open sites (BSI, 2014), whereas the baseline noise level, N_{Lbl}, was determined from the Department of Transport procedure in *Calculation of Road Traffic Noise* (Department for Transport, 1988). H_V and A_V were obtained according to the method described by the UK government Interdepartmental Group on Costs and Benefits Noise (IGCB(N), 2010); K_1 was suggested by Matthews and Allouche (2010) to reflect the duration of the noise.

Accidents

The increased frequency of accidents associated with the presence of roadworks and the associated costs were valued using the human capital technique (Gilchrist and Allouche, 2005; Morgan *et al*., 2011). In order to calculate the increased frequency of accidents, all factors other than the presence of traffic management, such as the prevailing weather conditions and road surface texture, are treated as a constant. An accident frequency with and without the presence of roadworks is provided by the Highways Agency (2016).

First, traffic flow (Q) input as the total number of vehicles per day (A_{ADT}) was converted to million vehicle kilometres (mvkm), by calculating the length of the works using the equation

$$Q = \frac{A_{ADT} \times t}{1\,000\,000} \times l \tag{10}$$

where t is the period of roadworks; l is the length of traffic management.

This was then multiplied by the frequencies for the 'with' and 'without' works scenarios, and the latter was deducted from the former to determine the increase using the equation

$$\Delta A = (Q \times A_1) - (Q \times A_2) \tag{11}$$

where A_1 is the accident rate with traffic management (personal injury accident (Pia)/mvkm); A_2 is the accident rate without works (Pia/mvkm).

Tool illustration

Two projects within the county of Staffordshire were chosen to demonstrate the developed procedure. The schemes were selected due to their contrasting locations; one was on the A449 Wolverhampton Road in Stafford town centre (the Stafford scheme) and the other was on the C0019 Dunsley Road in Kinver village (the Kinver scheme). Pertinent aspects of the two schemes are summarised in Table 5. The weightings result calculated using Equation 1 (see the section headed 'Technique development') are given in Table 6.

Table 5. Pertinent aspects of the two schemes

Scheme	Traffic (A_{ADT})	Speed limit: mph	Length of scheme: km	Trench width: m	Lanes affected	Road age: years	Partnership size	Innovative factor
Stafford scheme	8916	30	3	1·2	1	5	2	Use of temporary foam concrete reinstatements
Kinver scheme	4645	30	1·96	0·9	1	15	12	NA

1 mph = 1 mile/h = 1·61 km/h
NA, not applicable

Table 6. Weightings determination of tier 1 and community and political tier 2 indicators

Tier 1		Tier 2	
Indicator reference	Weighting	Indicator reference	Weighting
W_e	0·5862 6306 6		
W_c	0·2931 3153 3	C_1	0·5025 38
		C_2	0·2156 20
		C_3	0·0477 23
		C_4	0·2341 19
W_p	0·1206 0540 1	P_1	0·5396 92
		P_2	0·1096 12
		P_3	0·2561 98
		P_4	0·0944 98

For the two selected projects, the commercially sensitive data associated with the impact on businesses could be analysed only once the scheme had started, and therefore, these could not be used within the proposed framework. It is worth mentioning, however, that Dunsley Road is located on a rural area with few businesses and residential frontages, and therefore, the impact on business frontages was estimated to be relatively low. The Stafford scheme is located on an arterial route, but the impact on business frontages in the vicinity of the scheme was also identified as relatively low.

The values of time and origin–destination trip-related data for both schemes were collected in collaboration with the projects' contractors.

Stafford scheme

An opportunity for joint occupation involving a national grid scheme to replace 3·74 km of gas main and a Staffordshire Highways scheme to resurface 3 km of carriageway was identified. The joint occupation cost savings for the seven monetised indicators of value determined using the procedure described in the section headed 'Technique development' are summarised in Table 7.

Using the process described earlier, the components of socio-economic cost are given in Table 8. By applying Equation 1, the total socio-economic net benefit for the Stafford scheme is 8·36.

Kinver scheme

Six sets of works were carried out as part of a joint occupation scheme involving 12 infrastructure owners and contractors. During the scheme development, a number of additional smaller-scale

Table 7. Summary of monetised benefits of joint occupation for the Stafford and Kinver schemes

Monetised indicators	Sum of costs of individual works: £		Cost when works combined: £		Joint occupation cost saving: £	
	Stafford scheme	Kinver scheme	Stafford scheme	Kinver scheme	Stafford scheme	Kinver scheme
User delay	1 917 744·83	45 380·13	920 517·52	15 126·71	997 227·31	30 253·42
Reduced asset value	35 545·94	14 593·05	0	0	35 545·94	14 593·05
Increased maintenance	144 000·00	70 560	0	0	144 000·00	70 560
Traffic management	82 951·07	69 678·90	39 816·51	23 226·30	43 134·56	46 452·60
Noise[a]	24 538·80	6816·58	22 382·80	6488·28	2 156·00	328·30
Accidents	559 501·61	139 913·05	268 560·77	46 637·68	290 940·84	93 275·37
Total	2 764 282·25	346 941·71	1 251 277·60	91 478·97	1 513 004·65	255 462·74

[a] The cost of noise is calculated on the basis that frontage residents would be subjected to construction noise on one occasion during the joint occupation works rather than twice if they were carried out individually

Table 8. Summary of indicator scores for (*a*) Stafford scheme and (*b*) Kinver scheme joint occupation scheme, bold values are associated with Tier 1 indicators

Tier 1 indicator	Tier 2 indicator	(*a*) Stafford scheme			(*b*) Kinver scheme		
		Score	Weighting	Weighted score	Score	Weighting	Weighted score
Economic		**10**	**0·59**	**5·86**	**3**	**0·59**	**1·76**
Community	Customer satisfaction	6·8	0·50	3·39	4·8	0·50	2·39
	Collaborative working	2	0·22	0·43	6	0·22	1·29
	Impact on amenity areas	4	0·05	0·19	7	0·05	0·33
	Innovation	7	0·23	1·64	8	0·23	1·87
	Total			**5·65**			**5·89**
		5·65	**0·29**	**1·66**	**5·89**	**0·29**	**1·73**
Political	Reputation	7	0·54	3·78	7	0·54	3·78
	Political cycles	3	0·11	0·33	3	0·11	0·33
	Political interest	8	0·26	2·05	6	0·26	1·54
	Location	9	0·09	0·85	6	0·09	0·57
	Total			**7·01**			**6·21**
		7·01	**0·12**	**0·85**	**6·21**	**0·12**	**0·75**
Socio-economic net benefit				**8·36**			**4·23**

works in the area were identified, including bus stop upgrades, gas main repairs, sewer connections and tree felling works.

Using the proposed approach, the joint occupation cost savings for the monetised indicators are summarised in Table 7 and the associated socio-economic net benefits (Equation 1) are given in Table 8.

Comparison

Table 8 compares the evaluated benefits of the two schemes in terms of economic, political and community benefits. It is evident that while the political and community benefits accruing from the two schemes are similar, the economic benefit resulting from the Stafford scheme is substantially larger and accounts for the majority of the disparity in the evaluated benefit arising from joint occupation within the two schemes. The difference in the evaluated net benefits is exacerbated by the expert panel weighting economic measures of benefit to be more than twice as important as community measures of benefit and almost five times as important as political measures of benefit.

Table 8 indicates that all monetised indicators are valued greater for the Stafford scheme than for the Kinver scheme, apart from the traffic management costs. It is evident that user delay is the most significant contributor to the economic benefit accruing for the Stafford scheme and contributes a benefit, which is 30 times greater than that of the Kinver scheme. This is primarily a result of the traffic levels using the Wolverhampton Road in the vicinity of the scheme being almost double those using the Dunsley Road also heavy traffic (LGV) being three times higher in Stafford scheme (see the section headed ‘User delay’).

Accident cost savings are the second most significant portion of the total economic costs. The benefits of accident reduction are greater for the Stafford scheme due to the greater traffic flow and the length of traffic management, which is 300 m longer than that for the Kinver scheme. The significant reduction in noise from joint occupation at both sites results in very little joint occupation cost saving. In part, this is due to Equation 9, which factors down the costs according to the duration of each work’s phase for the individual and combined scenarios. The duration of the individual works assumes that the works are carried out continuously; for example, the Kinver scheme assumes that without joint occupation, the water main replacement works would have immediately followed on from the electricity works. Evidently, this would not have been the case and it could be argued that this assumption underestimates the level of annoyance. The incorporation therefore of an approach which considers the frequency of construction noise, in addition to the duration, could improve accuracy.

Despite lower traffic levels, the traffic management cost saving for the Kinver scheme is approximately 8% greater than that for the Stafford scheme, and this is because the joint occupation for the Kinver scheme is 5 days longer than that for the Stafford scheme (cf. Equation 7).

The benefits of joint occupation are significant when considering the increased maintenance and reduction in asset value costs associated with the physical destruction of the road pavement. For the Stafford scheme, the combined maintenance and reduction in asset value cost savings accruing from joint occupation are approximately 110% greater than those for the Kinver scheme. This is a result of the Stafford scheme occupying an approximately 50% larger area of road surface and the age of the Wolverhampton Road, which is 10 years younger than the Dunsley Road (see Table 5). For both schemes, it was assumed, partly for reasons of simplicity, that significant increased maintenance costs or a reduction in asset value would not occur for the joint occupation scenarios. These assumptions were made as the increased and joined-up length of the combined schemes would allow for a different reinstatement surface treatment – namely, resurfacing – compared to the type of reinstatements that would occur on smaller single schemes (i.e. patching). It is the latter type of treatment that is likely to cause increased road deterioration and result in a reduction in asset value and increased later maintenance costs.

The score associated with community benefit resulting from joint occupation for the Kinver scheme is marginally higher than that for the Stafford scheme (Table 8). Although for Kinver the customer satisfaction component of the score is lower, the other three measures of community benefit (collaborative working, impact on amenity areas and innovation) are higher.

Stafford’s score for the customer satisfaction measure of the impacts of joint occupation was higher than Kinver’s since the Stafford scheme is within an urban area, which has a higher density and proximity of residential and commercial properties than the rurally located Kinver scheme. Conversely, the Kinver scheme achieves a higher score for the impact on amenity areas measure due to its proximity to areas of public open space and the presence of tourist attractions in the vicinity of the scheme. The more favourable scores for collaborative working and innovation indicators for the Kinver scheme are because of the number of asset owners and contractors working in partnership to deliver the scheme. This is more evident for the collaborative working indicator than the innovation indicator because significant innovation was introduced at Stafford by the use of temporary foam concrete reinstatements to reduce the length of carriageway under traffic management.

As far as the political indicators are concerned, the scores for the reputation and political cycle are the same as both schemes were undertaken in the same year and, as both fall within Staffordshire, subject to the same local election cycles. Those for political interest and location are greater for the Stafford scheme due to the Stafford scheme being located within the county town.

Concluding remarks

This paper has described the development and use of a novel tool for evaluating the economic, social and political benefits of the joint occupation of highway schemes. For the development of the tool, a number of techniques described in the literature were explored to value benefit, including those that are suitable for quantifying benefit in monetary terms and those which provide qualitative measures of benefit. A hybrid approach was chosen that utilises expert opinion within an AHP-MCA, which combines and evaluates a variety of quantitative and qualitative indicators of the benefits of the joint occupation.

Conclusions and findings

The applicability of the prototype tool was demonstrated through an analysis of two joint occupation schemes in Staffordshire, UK. The schemes have demonstrated that the tool is applicable for

- valuing the joint occupation cost saving associated with economic indicators
- evaluating the benefit of joint occupation by combining economic, social and political measures of benefit.

For the two schemes considered, the Stafford scheme was found to have a socio-economic net benefit of 8·36 with a cost saving of £1·51 million when considering economic indicators of benefit only and the Kinver scheme was found to have a net benefit of 4·23 with an economic cost saving of £0·255 million.

Limitations and further work

It is recognised that further refinement of the prototype tool is both desirable and necessary. In particular, a number of economic indicators of benefit were selected on the basis that their data requirements are not considerable. These indicators therefore may be oversimplistic in determining benefit, and further development of the proposed approach should investigate whether more robust data-intensive methods will provide sufficiently improved accuracy to warrant the use of more data.

In particular, changes in road use costs associated with road pavement surface condition were not calculated since it would be problematic to quantify and compare these for multiple single openings and joint occupation. It may be expected that savings would accrue from having the road sections resurfaced initially, but that over time, the accelerated deterioration, which may be expected to result in the vicinity of the openings, would eventually lead to increased road use costs over time. The changes in road use costs, however, may not be significant for the two schemes considered, as the scheme lengths are relatively small, vehicle speeds are relatively low and the roads are reasonably maintained. Nonetheless, a net present value approach, using an appropriate economic tool such as HDM-4 (see Odoki *et al*. (2013)), could be utilised to quantify the savings accruing from single and joint occupation, but this would require extensive data and an analysis of deterioration related to the size of the openings in vicinity of the schemes over a number of years.

The approach utilised the AHP process to determine, using expert opinion, the relative importance of the economic, community and political measures of benefit, as well as the relative importance of the indicators contributing to the community and political measures. The application of the approach demonstrated that the output of the developed model was very sensitive to the weightings; therefore, it is recommended in any uptake of the model that the AHP process be used with care.

Additional transparency could be achieved by canvassing public opinion when determining the scores and weights of benefits.

Nevertheless, the use of the developed tool can encourage joint occupation, increases the transparency of decision making to all stakeholders and reduces the subjectivity of the current processes used by the industry. The tool provides the ability to prioritise schemes, and its outputs are understandable and can be related easily to other schemes. Further, the tool can assist emerging infrastructure service providers who have a greater commercial aspiration for the benefits of joint occupation working to be captured. Such companies are responsible for maintaining a number of assets within the same locality, and the accumulation of cost savings from joint occupation can increase profit margins.

Importantly, the ability to rank joint occupation opportunities provides the public with confidence that the impact of utility works on road users and nearby residents is taken into account when developing schemes.

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